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Visibility on the Road

By A. J. HARRIS, B.Sc.

Summary

Existing methods of measuring the visibility of an object or of assessing the visibility in an installation are discussed. The ideas underlying the concept of visibility are then analysed with the intention of making clear the nature of some of the difficulties which have given rise to controversy.

One must distinguish between the visibility of an object and the visibility in an installation. The latter is best regarded as an assessment of all actual or potential visibilities in the installation. There has been controversy as to the correct scale for the visibility of an object and about the meaning, if any, of the numerical values given by such scales. It is concluded that all scales which put objects in the same order of visibility are equally valid, but some are more convenient than others because they are more simply related to the visual phenomena vital to the task of the observer: in this case safe driving.

The attempt to represent the visibility in an installation by a single number is an attempt to put in order of merit the totalities of actual and potential visibilities in different installations. It is concluded that no useful meaning can be attributed to a comparison of these totalities in terms of visibilities alone. Any such comparison breaks down in certain cases and these are likely to be just the cases in which guidance is most needed. Installations may be compared, however, in terms of safety. The visual safety of an installation, as distinct from the visibility in an installation, can therefore be represented by a single number. The practical difficulties in the way of obtaining the visual safety are discussed. Progress seems to depend on gaining an understanding in clear numerical terms of the part played by visibility in the causation of accidents. Present knowledge is extremely meagre.

Introduction

The word "visibility," as used with reference to street or vehicle lighting, appears to have no precise generally agreed meaning, and there is certainly no universal method of measuring or estimating it. There exist, therefore, a number of distinct quantities to which the title visibility has been applied. There are also certain quantities derived from the visual aspect of the street, such as "revealing power"[1], which appear to play a role like that of visibility, but which their authors distinguish sharply from visibility as they understand it.

The International Commission on Illumination set up in 1955 a Working Party on Street Lighting. Among the recommendations for its programme of work is the following[2]: "A number of so-called 'visibility meters' has appeared, but it is felt that there are theoretical difficulties in the measurement of 'visibility' in a street as commonly understood. There is need to settle this point, to explore definitions of 'visibility' and related functions such as 'revealing power' and to decide whether further work is necessary."

The present paper is divided into two parts. The first contains a brief discussion of the methods which have been put forward for defining and measuring visibility and related quantities. The second part contains an analysis of the idea of visibility. The intention of the analysis is mainly to clarify some of the difficult points in the definition and evaluation of quantities like visibility rather than to defend a single point of view.

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(1) A Survey of Definitions of Visibility and Methods of Measurement.

(1.1) Introduction

By the "visibility of an object" we mean, in some sense, the ease with which the object can be detected or seen. By the "visibility in a street" we mean in some still vaguer sense the ease with which we see things, or expect to see things, in that street, without necessarily specifying what things there are to see. There have been many attempts to make these notions more precise, to give them a strict numerical form, so that visibilities can be compared with that degree of certainty which only numerical processes seem to give. It must be admitted that some authorities[3] regard the visibility in a street as a quality which by its very nature is incapable of measurement. They may even include qualities like comfort or pleasant appearance, but in this paper such wider meanings are not accepted. Here visibility relates only to seeing or detecting, but in the street the seeing is always for a purpose—for well regulated driving and the avoidance of accidents.

(1.2) Visibility of an Object

There are two main ways of regarding the visibility of an object, the subjective and the objective. The first of these generally runs to meters, the second to statistics.

Objects differ in visibility. Some are invisible, some only just visible, some clearly visible and so on. We are aware of these differences subjectively; all that is needed is a method of measurement, and a numerical scale. These are usually supplied by a visibility meter. This contains a device, a density wedge or the like, for making seeing more difficult. This can be adjusted until an object viewed through the meter is only just visible. The fundamental point about the use of a meter is that it is assumed that objects which are only just visible at the same setting of the meter have the same visibility. Each setting of the meter corresponds therefore to a single level of visibility, and if the movable part of the meter is graduated in some way we can use the readings of the meter as a scale of visibilities. Although some visibility meters have scales almost as meaningless as this, others are calibrated on a set of standard visibilities—the visibilities of a standard set of objects viewed in prescribed conditions of lighting. Since the standard objects differ among themselves only in one respect, in size perhaps or in contrast, a measure of this variable factor is regarded as a measure of visibility. For example, Luckiesh and Moss calibrated their meter on black spots of different sizes, and took as the visibility the angle which the spot subtended at the eye[4].

Clearly one may construct meters and scales in great variety. The visibility of an object depends on many things, among which size, brightness and contrast are of greatest importance, and one or more of these may be varied by the meter to reduce the visibility to the threshold state. Most meters which have been described vary both the brightness and the contrast of the scene, but they vary them in different proportions. The Luckiesh-Moss meter[4], the Duckler meter[5] and the Horton meter[6] all employ some form of density wedge. Such wedges generally diffuse the light as well as absorbing it, and different materials give rise to different amounts of diffusion. It has been objected that, since all meters of this type darken the field of view, they alter the adaptation level of the eye in the process of measurement and are therefore unsatisfactory. The Cottrell meter[7] and the Simmons-Finch meter[8, 9] are designed to vary the contrast and to keep the brightness of the field of view more or less constant. Of these, the Simmons-Finch, which appears to be the latest and most elaborate of visibility meters, was designed especially for street work. The field of view is wide so that the street lamps can be seen, and so that the glare from them can have its true effect upon the visibility. Only the central 2 deg. or 3 deg. of this wide field is affected by manipulating the meter. A uniform

brightness is superposed on this central region while the light from the scene itself is cut down; the two changes are coupled so that the combined brightness remains almost constant. The instrument is calibrated on objects of equal size but different contrast, the percentage contrast being taken as the measure of visibility. The Cottrell meter determines the ratio of the true contrast to the contrast in the threshold state, and it is suggested that this, called the "contrast sensitivity," "may well be a useful index of visibility."

One might think that, in spite of the variety of meters and calibrated objects, it would be possible to compare the different meters and so convert from one scale into another. Unfortunately this is not so. Dunbar[10] showed that the meters do not necessarily arrange objects in the same order of visibility. Objects which have equal visibility according to one meter may have different visibilities according to another. They agree, of course, about the standard objects, because these are used in the calibrations, but for other objects the results are not necessarily consistent. He also showed that glare might produce different effects with different meters, so that if glare is present, as it usually is in street lighting, it may give rise to further discrepancies. The fact that different meters cannot be made to agree has raised fundamental doubts about the theory of visibility on which the use of meters is based.

When visibility is treated as an objective phenomenon there is less difficulty about the scale. It is found, for example, that if an object is exposed only for a short time an observer may or may not see it. If the experiment is repeated many times the proportion of times in which the object is seen is found to vary from object to object, and it is found that objects which are definitely more visible when judged subjectively are detected in a larger proportion of cases. The proportion of times seen, or the average time required for detection, or some analogous quantity, is therefore accepted as a measure of the visibility from the objective, statistical, point of view[10].

The statistical type of visibility has not been much used in street and vehicle lighting except in research investigations, since no handy meter for this type of work has been devised. De Boer[11], however, used objects which appeared suddenly, or grew progressively darker, or grew in size, and measured the time after appearance at which they were first detected. The average values of the times were regarded as measures of visibility. In vehicle lighting it is usual to measure the distance at which an object is seen; the average of a number of readings is called a "visibility distance"[12]. English[13], in assessing street lighting, used a circular disc with a notch cut in the circumference. This was placed in the street, the disc was spun, and came to rest with the notch in one of the twelve clock-hour positions. An observer tried to detect the position of the notch, the percentage of correct observations being taken as the visibility.

(1.3) Visibility in the Road

The visibility in a road, regarded subjectively, is usually judged by observers who view the road when it is almost empty and compare it with other roads or with memories of other roads. The aim of these comparisons is to put the roads in an order of merit, and it is unusual to ascribe any numerical value to the visibility. A study of this comparison process in a more systematic form has been given by Stiles and Dunbar[14].

The usual way of arriving at a numerical value for the visibility in a road is to regard it as some kind of statistical entity, a sort of average, to be derived from the visibilities of objects in the road. The quantities arrived at differ in a variety of ways. Most of them are averages of visibilities, but the visibilities are measured on a variety of scales, and revealing power is not an average visibility at all[1], but the percentage of the visibilities whch are judged adequate for safe driving[18]. The

averages, too, are found in different ways. Horton[6] and Reid and Chanon[16, 17] determine the visibility of an object fixed with respect to the vehicle, and average this for a number of points spaced equally along each traffic lane. English[13], de Boer[18], and Simmons and Finch[8, 9] fix the position of the observer and study the visibilities of objects situated at an array of points some distance ahead of him. Each investigator uses a different array. Waldram, in calculating revealing power[1], fixes the observer and then averages along each line of sight from the observer to its termination at the road surface. The reflection factor of the object is treated differently in different systems. For evaluating revealing power the objects are assumed to have a distribution of reflection factors representative of pedestrian clothing[1, 19]; in all other cases only a single reflection factor is used. This value may be chosen to represent a particularly hazardous situation or an average situation, and values chosen have ranged from 2 to 12 per cent.

This wide variety of systems and numerical scales suggests either that what is aimed at is so difficult of attainment that each investigator has devised his own and different approximation to it, or that there is indeed some uncertainty of aim. We should like to know which of the differences are only apparent and which are real and fundamental. To clarify our ideas we therefore turn to an examination of the notions on which the ideas of visibility seem to be based.

(2) Visibility: A General Analysis

(2.1) Introduction

A brief summary of the argument of this section may be helpful at this point. First we consider the relationship between measurement and the process of putting things into an order of merit. We conclude that an order of merit implies a scale, that is, the possibility of representing the quantity by a single number. The numerical values of the scale may be arbitrary, except that they must preserve the order. All such scales are equally valid, but some may be more convenient than others because they are more simply related to other phenomena of importance. Scales of visibility of single objects seem to be of this kind.

"Visibility in a street" is then considered. This is best thought of as some measure of the aggregate of all actual and potential visibilities in the street. If this is something by means of which streets can be arranged in order of merit, then it must be possible to represent it by means of a single number. It is concluded that this is not possible, for no method of comparison sufficient to establish an order of merit can be found. Therefore if two installations are compared it may be meaningless to ask, "Is the visibility in one better than in the other?" Streets may be compared, however, in terms of visual safety. We distinguish therefore between a visibility factor, which probably does not exist, and a visual safety factor, which probably does. The relationship between visibility and safety is discussed and an attempt is made to state what must be known in order that the visual safety factor should be calculable. Comments on some of the existing definitions of visibility are made in the light of the conclusions reached.

(2.2) Order and Scale

Whenever a number of objects can be arranged in an order of merit, it is possible to allot to each an arbitrary number so that the higher the object in the order of merit the greater the number attached. These arbitrary numbers may then be regarded as measures of the quality by means of which the objects were ordered; they provide in fact a numerical scale.

It has been questioned in connection with visibility[20] whether such a scale is valid, and whether one can say that anything has been measured or that the numerical values have any meaning when such a scale is used. It seems unnecessary to enter into

a philosophical discussion of the validity of the procedure. It will probably be acceptable if it can be shown that some well-established physical quantity has a scale defined in the same way. This appears to be the case for temperature. The sensations of hot and cold are no more numerical than the sensation of ease of seeing, but they enable objects to be placed in an order of hotness. Two levels of hotness were arbitrarily denoted by 0 deg. and 100 deg. and the other temperatures were defined by means of the expansion of some arbitrarily chosen substance. That is, it was found that the order of hotness was the same as the order defined by the expansion, and the expansion was used simply as a convenient way of getting numerical values—but essentially the scale was arbitrary. Every expansible substance defines a different scale of temperature, which does not necessarily agree with the others except at the points 0 deg. and 100 deg. Nowadays, of course, these scales have been superseded by the thermodynamic scale, because it depends on properties which are the same for all substances and is more simply related to a vast number of physical phenomena. It is therefore more convenient. The old scales are not invalidated, however. Provided they agree in giving the same order of hotness to bodies at different temperatures, any scale converts into any other, and the laws of physics can be as correctly expressed in the gas scale, or indeed any quite arbitrary scale, as they can in the usual thermodynamic scale.

It seems, therefore, by analogy with the scale of temperature, that if an ordering principle exists it can be made the basis of a scale. The scale can be quite arbitrary except that it must preserve the order. Nevertheless, some scales may be more convenient than others because they are more simply related to phenomena of importance. Conversely, if no ordering principle exists it is not possible to have a scale in the usual sense and it is useless to seek one. A scale, if it existed, would itself provide an ordering principle.

Thus those who believe that visibilities (however defined) can be placed in an order of merit should believe in the possibility of representing them by single numbers, while those who deny that a single number can represent a visibility should believe that, in some cases at least, it will not be possible to arrange visibilities in order of merit, even by the exercise of judgment[21].

There exist, however, what are called partially ordered systems. In these it is not possible to arrange all the items in order of merit; any two taken at random may or may not be orderable. For example, the revealing power of an installation is a quantity which is defined by a distribution of numbers—the individual revealing powers of the elements of road surface. If two installations A and B are being compared, and it is found that the revealing power is greater at every point in A than in B, then there is an obvious sense in which it can be said that the revealing power is greater in A than in B. A and B can therefore be put in order. But if the revealing power in A is greater than in B at some points and less than in B at others, there is no obvious way of putting A and B in order; the relationship greater or less simply does not apply.

Quantities which are represented by groups of numbers generally form partially ordered systems. Conversely, quantities which cannot be ordered must be represented, if they can be represented numerically, by more than one number. It is sometimes implied however, when dealing with partially ordered systems such as revealing power, that an experienced person can interpret the numerical situation and decide the order of items which on the numerical basis alone cannot be put in order. When this is so the numerical values are being superseded, and there is then no reason why the items should not be represented by single numerical values on an arbitrary scale, but this is the scale determined by the act of judgment not by the original numerical basis.

Of course, where ordering is based on subjective judgment it is usually a much more uncertain thing than when based on measurement. Different observers do not

necessarily arrange things in the same order, and the same observer may vary his order from day to day. Even if observers are capable of arranging any two objects in order it does not necessarily follow that they can put a whole collection of objects in order in a consistent fashion. Some of these difficulties are overcome by means of repeated trials or panels of observers[14]. Problems of this kind have been much studied in connection with food tasting, or judging the consistency of cheeses: subjects in which there is at first nothing but subjective judgment to work with. Special statistical techniques have been developed for dealing with some of the problems involved[22]. In what follows it is assumed that by one or other of the means available an agreed order can be got.

(2.3) Visibility of Single Objects

It is desirable to make the notion of visibility a little more precise at this point. An object only has a definite visibility when the conditions of observation are completely defined[10]. An object in the street does not have the same visibility to a driver at rest with ample time for observation as it does to the same driver engaged in driving his vehicle. When visibilities are referred to in what follows some definite conditions of observation are implied.

(2.3.1) *Visibility scales*

As explained, an order of merit implies a scale, and that scale can be quite arbitrary. Any scale is valid provided the order is preserved. If, therefore, by subjective judgment, we can put all objects, or all installations, in order of visibility, we can ascribe to visibility any numerical scale we find suitable. The objection to the scales given by meters is not that they are arbitrary but that, because they disagree amongst themselves, they cannot all be giving the subjective order they purport to give. Only if they have been shown experimentally to give this subjective order can they be regarded as acceptable.

It is possible, of course, to regard the meter as independent of any implied subjective order; the meter determines some order and this order shall be by definition the order of visibility. The problem then is to know why one meter should be adopted rather than another.

Meters, as generally used, require a certain minimum of time, and freedom from distraction, for the taking of a reading. The scales of visibility that they provide cannot therefore be extended to conditions of observation in which these minimum requirements cannot be met. The visibility they give tends to be thought of as a function of the object and its background and to be independent of the other conditions of observation, since these are effectively constant while observations are being made.

The objective scales of visibility are, as we have seen, derived directly by experiment. When an object is exposed for a short time, there is the proportion of instances in which it is detected. Or, as in the work of de Boer[11], if an object is suddenly exposed to view, the time which elapses before it is seen may be measured and the average time, or better, the inverse of the average time, may be taken as a measure of the visibility.

It is clear from the examples just given that the numerical values of the objective scale are no more unique than those of the subjective scale. Many different objective measurements of visibility can be derived from the results of one experiment. For instance, instead of taking the inverse average time of the last example, one could take the percentage of cases in which the time taken to see the object is less than t seconds, where t is any arbitrary number. All such measurements would be equally acceptable if they agreed in giving the same order of visibility. Scales which agree in giving the same order are measuring the same thing, even though their

numerical values are quite different. They are like the different scales of temperature; they transform directly with one another. It is only when they result in different orders that different measurements represent different entities.

Unlike the scales given by visibility meters, some of the objective scales based on statistical measures of whether something is seen or not have the advantage that they are applicable to all conditions of observation; from the observer who is concentrated on a single task to the driver in a busy street who has to divide his attention between a variety of objects.

(2.3.2) *Convenience of scales*

Visibility scales may be selected on grounds of convenience. Convenience is not to be judged by the capacity of the scales to represent the order of visibility, since all valid scales do this equally well. It is when we wish to relate visibility to some other quantity, safety for instance, or to combine visibilities and find averages, that the numerical nature of the scale becomes important and some scales are found to be more convenient than others.

The objective scales we have been discussing are more directly relevant to road traffic problems than arbitrary subjective scales like that used in calibrating the Luckiesh-Moss meter. The most important visual requirement in the street would seem to be to detect the presence of an object or a feature of the roadway soon enough to be able to take action to deal with it. The time available for observation is limited. The probability of detecting the object within a certain time, or better, the probability of detecting it before it has approached to within a certain distance, seems to be an essential numerical feature of the visibility situation in a street. Visibility scales based on such probabilities are relevant in a way that arbitrary scales are not. The ideal scale for this type of work would be one which expressed the visibility directly in terms of these probabilities. Arbitrary scales can be used in a meaningful fashion only if the relation between visibility and probability is known; the use of this conversion factor is equivalent to the direct use of the ideal scale.

When it is desired to combine visibilities to form averages or the like, the statistical types of visibility are generally much easier to combine in ways which are significant. Not all are equally convenient, however, when looked at from this point of view. For example, if as a result of repeated experimental runs we know the probabilities with which various types of objects were seen before they were within some distance d of the vehicle, and if we knew in what proportions these objects would be encountered on the road, then the probability that an object of any of these types would be seen before distance d would be an average of their individual probabilities weighted according to the proportions in which they would be encountered. This is a quantity whose meaning is clear (it is the same as that of the elements out of which it is built) and it is closely related to the safety aspect. But had we adopted as a measure of visibility the distance D ahead of the vehicle beyond which the object was seen in 95 per cent. of trials, we should not have been able to calculate, for an assortment of objects, the distance beyond which 95 per cent. of the assortment would be seen. To do this we would require more information about the distribution of distances for each object. Nor does this latter measure seem as relevant to the problem of safe driving. The different distances obtained for the different types of object represent quite different degrees of danger, so that, if we are mainly interested in the safety aspect, they cannot be simply combined. It appears that the choice of scale should be determined by the use to be made of it. This aspect is discussed in Section (2.5) which deals with the relationship between visibility and road safety.

(2.3.3) *Some additional comments on the definition of visibility*

A point which seems to be of practical and theoretical importance, but which does not appear to be much discussed, is whether the order of visibility remains unchanged

when the conditions of observation are varied.[23] This is of practical importance because visibility measurements can be made comparatively easily in the laboratory, or in static conditions on the road, but only with difficulty and at great expense under real-life driving conditions. It would be agreed that what was just above threshold visibility under laboratory conditions might be well below threshold on the road. The numerical measures would be quite different in the two cases, but if the order of visibility was retained the problem would simply be one of determining the relationship between two scales. If the order was different the matter would be much more complicated. But the existence of a unique order would also imply that there was a basic visibility independent of the conditions of observation. It seems to be implied in many researches in visibility that this unique order exists: for instance, the use of meters as explained in Section (2.3.1) implies it. One also tends to think of the visibilities of objects as basically determined by their sizes, brightnesses, contrasts, etc., all of which are independent of the observer. The probability of detecting an object is then regarded, not as the visibility itself, but as something determined by a basic visibility and the conditions of observation. (The term "basic visibility" has been used for visibility in this sense in one or two places in this paper when it was difficult otherwise to express the meaning and where misunderstanding seemed unlikely.) The existence of such a fundamental order seems likely, at least within a restricted range of circumstances. But one might expect, perhaps, that the order of visibility of steady and flashing lights might be reversed when viewed first against backgrounds containing a preponderance of steady lights and then of flashing lights.

Whether visibility is taken in the basic sense, or as defined in this paper, it is assumed that the visibility of an object can be represented by a single numerical value. But in the discussion of probability and safety in Section (2.3.2) it appears that the single visibility transforms itself not into a single probability of detection but into a distribution of probabilities. To specify the situation completely we require not merely the probability of detection at some arbitrary distance d^1, but the value for every distance d. Unless this distribution depends only on a single parameter, even the visibility of a single object may not necessarily be an orderable quantity from this point of view. We assume, however, in what follows, that this is so, and that the visibility of an object can be represented by a single number.

(2.4) Visibility in a Road

From the point of view adopted here, the visibility in a road has something to do with the visibilities of the various permanent features of the roadway, kerbs, obstructions, etc., and with the visibilities of objects which might be encountered in the road, such as pedestrians or vehicles. If we assume that each of these has a definite visibility when viewed from any particular point, then we are concerned with an aggregate of permanent and possible visibilities. In seeking to put streets or installations in an order of merit it seems that we are really trying to put these aggregates in order of merit, and therefore to find a way of representing the aggregates by single numbers. To distinguish between the visibility of a single object and some measure relating to an aggregate of visibilities, we shall call such a measure an aggregate visibility factor. Such measures may or may not try to take into account the fact that a given visibility does not have the same safety value if it refers to objects differently situated in relation to the vehicle. To distinguish between them, an aggregate visibility factor which takes safety into account will be called an aggregate visual safety factor.

It is clear that since we are dealing with aggregates of numbers (visibilities) it is quite possible that they will not form ordered systems. Indeed the attempt to find an

aggregate visibility factor, that is, to place these aggregates in an order of merit, will fail unless every pair of aggregates can be put in order.

Let us, however, first consider the view of those who believe that streets can be placed in order of visibility by subjective judgment. A numerical scale could be created by an observer, or panel of observers, placing streets in order of merit and allotting numbers to the various streets. The standards of visibility might exist subjectively in the observers' minds, or be physically embodied in certain streets (all streets in fact which had already been allotted a visibility value) just as the Luckiesh-Moss scale is embodied in certain black spots on a white background. Taking certain streets as standards has an advantage over trying to hold a number of different criteria in mind. The only judgments one has to make are those of better and worse, and one can refresh one's memory of the standards by reinspecting the streets; one is not entirely dependent on retaining a subjective standard at a constant level over a period of time.

Although it may seem rather far fetched to set up in this way an ordered scale for the visibility in a street, something very like it is, in fact, the usual practice. Most lighting engineers would be prepared, for want of a better means of comparison, to form a judgment on a number of different installations by viewing and comparing them. All that is omitted is the numerical value and, as this may be arbitrary, the omission is not fundamental. It can hardly be said, however, that the aggregates of visibilities really enter into these comparisons.

As explained in Section (1.3) the usual way of obtaining a numerical value for the visibility in a street is to build up an aggregate visibility factor or aggregate visual safety factor from the individual visibilities of objects in the street. Reid and Chanon ([16, 17]), Finch and Simmons([8, 9]), English([13]), and Waldram([1]) have suggested methods of combining individual values into a single value, usually by taking a weighted average.

It is customary to choose the weighting factors without much consideration of the scale of visibility employed. Constant values are usually chosen : it is desirable to look a little more closely into this procedure. Since the purpose of the single figure must be to express an order of merit, those roads which have the same numerical value must be judged to have equal visibility. If, however, the scale on which the individual visibilities are measured is changed, the roads which were previously judged to have equal visibility will not have equal visibility in the new system unless the weighting factors are also changed. In general the weighting factors will have to depend on the visibilities themselves; they will not be constants. Thus, it is by no means self-evident that one can select a simple weighted average of the individual values—one in which the weighting factors are independent of the visibilities—without careful consideration of the nature of the basic visibility scale. For example, the Simmons-Finch scale is numerically a measure of contrast, whereas Dunbar would seem to favour a probability of detection, and it has been shown that probability of detection is not at all simply related to contrast([10]). Thus if visibilities were weighted by some simple scheme with constant weighting factors, the two scales must inevitably lead to contradictory results. If the weighting factors were independent of the visibility values in one system, they would have to depend on the visibility values in the other, in order that the results should be compatible.

There has been no general agreement as to the suitability of the various numbers which have been put forward in this way as aggregate visibility factors or aggregate visual safety factors. Is there any criterion by which suitability may be judged? Those who hold that visibilities of streets can be put in order of merit subjectively have, in theory, merely to check whether the numerical criterion gives them the same order of merit as the subjective appraisal. All criteria which give the same order give equivalent scales. But those who do not hold that they already know

how to arrange streets into an order of merit have to find some other criterion for judging the various numbers which may be constructed from the elementary visibilities. Since the quantities put forward seem to be visibilities, but are really visual safeties, this point is discussed in Section (2.5) on the relationship between visibility and road safety.

(2.5) Visibility and Road Safety

(2.5.1) *An aggregate visual safety factor*

It should be possible to put lighting installations in an order of safety. It should be possible, therefore, to find an aggregate visual safety factor. To compare two installations one could install both on the same stretch of road, and by using them in turn obtain the accident rates under identical traffic conditions. The accident rates, reduced to some common denominator (e.g., cost), would then put the installations in an order of merit. There would exist an order of visual safety and a numerical scale on which to express it.

Although it therefore seems possible to determine aggregate visual safety factors experimentally we are concerned here with the problem of deriving them from the aggregate of visibilities by calculation. It seems unlikely, however, that the accidents and the visibilities can be linked except through intermediate stages which are complex and largely unknown. Empirical relationships are fragmentary. As far as has been ascertained from statistical studies of accident rates under different conditions of lighting, daylight is better than dark[24], and very good Group A lighting is better than very poor Group A[25], and a few figures have been put forward with less confidence for other grades of lighting[26]. It has not yet been shown that the type of installation (high-angle, cut-off, etc.), colour of light, or type of road surface makes any difference. The relative importance of different parts of the street has not been determined. The difficulty is mainly the inadequacy of the statistics and the small scale of the experiments. When the numbers of accidents are small, chance effects and secular changes largely swamp the finer details.

There is little experimental information, therefore, about the relationship between visibility and the chance of an accident. When the problem is considered theoretically, and in detail, it is seen that things are fairly complicated. Even at its simplest, three probabilities at least are involved in the occurrence of a collision between a vehicle and an object in the roadway. There is the probability of there being in the roadway an object following a certain path, the probability that the object will be seen at some point of that path, and the probability that having seen the object at that point the driver will be unable to avoid a collision. The probability of there being an object at any point is a function of the type of traffic, road layout, etc. Cyclists are more probable near the kerb than in the middle of the road; pedestrians may be found anywhere across the road but they normally begin their crossing at an adequate distance ahead of the vehicle, although some step off the kerb just ahead of the vehicle. The probability of first seeing the object at any point depends largely on its visibility and on the conditions of observation, i.e., the rest of the visual field and the difficulty of the task facing the driver. Finally, the probability of a collision depends on the position of the object relative to the vehicle when first seen, the path it is following, the speed of the vehicle and the capacity of both driver and obstacle to avoid the collision. If these probabilities are known the resultant probability of collisions in that street can be found by multiplying the three probabilities together and summing the product over all the possibilities. It seems unlikely, when the situation is put in this way, that the result should be a simple weighted average of the visibilities on some arbitrary scale. How closely it would approximate to this, however, depends on the nature of the probability distributions involved and how closely the scale of visibilities approximates to a scale of probabilities of detection.

Unfortunately almost nothing is known about these probabilities. No existing visibility scale is expressed in terms of the probabilities of seeing the object in the road under actual traffic conditions. Even English's scale refers to a very small object as an element of detail in a larger one and the object is viewed by an observer at rest. Consequently, it is not even known in what proportion of accidents visibility is really an important factor. The majority of accidents take place in daylight when visibility, in the sense in which the term is used in this paper, must be quite high. If few daylight accidents can be described as visibility accidents, a large proportion of night-time accidents are probably not visibility accidents either.

There is another and more general reason why the relationship between visibility and the probability of accidents is complex: the driver adjusts his driving to some extent to his estimate of the visibility. He varies the visibility by adjusting the conditions of viewing. The accident situation is not dependent simply on the basic visibility but on the interaction of the basic visibility and the driver's subjective estimate of that visibility.

One would expect that in reacting to the visibility the driver would tend always to reduce his sense of danger to some fixed acceptable level. It might therefore be expected that whatever the basic visibility the chance of an accident would remain constant. There are a number of reasons why exact constancy should not be expected, and indeed there is evidence that it is not achieved, since improved lighting has been shown to reduce accidents in some cases. But because the driver reacts at all in this way the probability of accidents estimated from visibilities for standard fixed conditions is probably incorrect and may be quite misleading.

Thus although it seems possible that an aggregate visual safety factor might be constructed for an installation, the practical difficulties in the way of doing so at the moment are very great. We therefore turn to the problem of constructing an aggregate visibility factor.

(2.5.2) *An aggregate visibility factor*

In seeking a suitable definition of the aggregate visibility factor we are trying, fundamentally, to put aggregates of visibilities into an order of merit in a way which shall not depend on questions of safety. Since the whole question of visibility on the road is one in which seeing in relation to safety is an essential feature, it is difficult to see what criterion is left if safety is abandoned. The only obvious meaning that can be given to the notion that one group of visibilities is better than another is that the visibilities in the two groups can be paired off in pairs of equal safety value in such a way that any visibility of the first group is greater than the corresponding visibility of the second. If this cannot be done we cannot attach a meaning to the idea that one group is better than the other. Thus, if all the visibilities of objects 100 ft. directly in front of the vehicle could be increased, there would probably be general agreement that the visibility at that point had been improved. Since the objects would have the same safety value the comparison could, in a sense, be made without reference to safety. The safety might have increased or it might not, but it would seem plausible to say that as far as visibility alone was concerned there had been an improvement. It could be argued that if the safety had not increased then the responsibility for this must lie elsewhere than in the field of lighting. On the other hand if the visibilities of objects at 100 ft. were increased while those at 200 ft. were diminished we should not know whether the net result could be regarded as an improvement without knowing what the differences meant in terms of safety. The side-stepping of the question of safety, which seems plausible in the case of a pure improvement, breaks down when we have to deal with an improvement at one point and a deterioration at another. In this case we do not see how the blame for a deterioration in safety can be shifted from the visibility to some other cause. As long as we leave safety out of consideration, and try to assess the aggregates in terms of the visibilities alone, we cannot compare all the

aggregates in a way that leads to an ordered system. No aggregate visibility factor is therefore possible: there is not necessarily any answer to the question "Is the visibility in A better than in B?"

(2.5.3) *Approximations*

Since, as has been shown, an aggregate visual safety factor could be found if we had sufficient information, whereas an aggregate visibility factor does not exist, how should we regard those quantities which were described in Section (1.3) and which purported to represent the visibility in a road? They appear to be aggregate visibility factors, because there is no elaborate weighting of the visibilities in terms of safety, but in fact there is such a weighting in a very elementary form. Certain objects are included in the averages; others are omitted. The omission of all objects within a distance of 100, 200, or 300 feet of the vehicle, according to the system considered, is justified on grounds of safety. Unless objects are seen at distances greater than these, it is argued, they will not be seen in time. Incidentally, such an argument, while it may give grounds for insisting that all objects should be seen at these distances, is not a sound reason for omitting nearer objects from an average which is intended to represent the situation in the road. But, in any case, considerations of safety have entered into the definition of these quantities and they are therefore approximations to an aggregate visual safety factor, in spite of appearances to the contrary.

Although evaluation of the true aggregate visual safety factor seems at present remote, these approximate factors enable us to embody what knowledge we have of visibility and safety into a single whole. Because they are not exact we must be careful not to ascribe much significance to small differences in their value. They will fail to give answers to some of the questions on which guidance is most desired. No one is much concerned with whether visibility is increased when an installation is raised to 10 times its initial light output with distribution unchanged. It is where there appears to be a mixture of good and bad that it is most desirable to know how to sum up the effects. For example, cut off lighting gives dark bands running across the street, while high-angle lighting tends to make them run along the street. We should like to know which was the safer, but it seems unlikely that this question could be settled at present by the calculation of visual safety factors.

If it is clearly understood that these approximations are not visibilities but visual safeties, and that the more they reflect our knowledge of the safety aspect the better, the more likely they are to develop into something really useful. Even while they may not be very accurate in placing installations in order of merit, they may be more efficient for certain other purposes, such as specifying limits below which the visibility in an installation should not be allowed to fall.

It is probable, however, that for some time to come more will be learned from point by point comparison of the aggregates of visibilities than from overall figures. But they must be compared in pairs of equal safety value. Waldram, in his account of revealing power([1]), laid little stress on the overall figure and emphasised that it was the individual values that were important. It is unfortunate therefore that even these are averages involving a wide range of safety values. As explained in Section (1.3), an elementary revealing power is the proportion of objects which reach the level of adequate visibility averaged along a line of sight. The visibilities of these objects, because of their variable distance from the vehicle, are of very different safety value. A much more significant array of numbers would be obtained if each referred to some point fixed with respect to the vehicle but averaged perhaps along the path of the vehicle through the installation after the manner of Horton([6]) or Reid and Chanon ([16, 17]). However, the practical and computational labour necessary to do this for a large number of points would greatly exceed that required for evaluating revealing power.

(2.5.4) *Conclusions regarding aggregate factors*

It seems, both from theoretical considerations and from the trend of development, that if we are to progress towards a single criterion of visibility for the street as a whole we must ultimately aim at an aggregate visual safety factor not a visibility factor. We must find out what the visibilities mean in terms of probabilities of detection and what detection at different points means in probability of accidents. Unless these things are known in numerical terms the real importance of the visibilities are not known, and no conclusions can be drawn except in cases where there is a uniform superiority on one side It seems impossible even to form a judgment as to these things in the absence of such information. For example, if the revealing powers ahead of a vehicle and just to left and right of it are 60 per cent. and 90 per cent., so that the proportions of objects not adequately revealed are 40 and 10 per cent., can it be assumed with any confidence that the relative importance of the visibilities (assuming danger levels at these two positions to be equal) is 40 to 10. The proportion of objects revealed in time to avoid an accident may be quite different from the figures of revealing power; perhaps 96 per cent. and 99.9 per cent. If so the relative importance will be as 4 to 0.1, i.e. 40:1. In order that it should be possible to weigh the importance of the visibilities in different parts of the field it is not enough that the numerical values should indicate whether the visibility is higher at one place than another; it is necessary that the relative importance should be correctly given. Thus, although criteria like revealing power seem attractive, the numerical values they provide are not yet known to be probabilities of detection or of accidents, and if this is forgotten they may lead to false conclusions.

(2.5.5) *Complex or simple criteria*

It has been argued[27] that complex constructions like revealing power are of little value, because conditions in an installation can vary so much with the weather, road surface wear, etc., that the figures only apply at specific times and places: a much simpler method of assessing the merit of an installation, it is said, gives all that is required. But the fact that the wetting of the road surface may completely change the visibility in an installation is not a reason for ignoring the change, but for taking it into account. It has proved easier to show that wet road surfaces affect the frequency of accidents than to show that any differences in type of installation do so[28]. It should be recognised that the visibility in an installation does vary with the weather and that the wet and dry situations should both contribute to an estimate of its merit.

There is a sense in which almost any fairly relevant simple measurement—lumen output, road brightness, etc.—will function as a figure of merit, as one of the approximate aggregate visual safety factors mentioned earlier. Installations are designed according to rules based on successful practice and therefore tend to be similar. An increase in lumen output probably means an increased road brightness (maximum, average or minimum), a diminished threshold contrast for safe seeing, and so on. Such criteria may work reasonably well as long as the installations do not depart too far from the norm. They become suspect, however, if the criterion itself begins to dictate the design of the installation, as "test point illumination" did at one time. For a correct measure of visual safety the exact opposite would be true: the more completely this dictated design the better. The approximate criteria are also of little value when the question at issue is the value of the differences in design between one installation and another rather than in the general level.

The virtue of the more elaborate measures of visibility is that they take into account far more of the factors on which the aggregate of visibilities depends. They are based on a closer understanding, and they may lead in turn to still better understanding, of how the physical features of an installation create the visibilities encountered therein. In spite of the inadequacies of the criteria we have, the more elaborate they are the more likely they are to give useful guidance.

In the future, the availability of automatic computing machines will make it much less necessary to attempt to avoid long routine calculations. It will be better to use meaningful numbers calculated by the machine, than to accept almost meaningless numbers simply because they can be obtained with little human labour.

(2.5.6) *Visibility in a very crowded street*

A point which always arises in discussions of visibility is whether visibility in a crowded street can be assessed in the same way as in an almost empty street. In all visibility systems the visibilities of objects have been measured against the stationary permanent background of the road surface or its surroundings. In the crowded street the background is frequently formed by other objects, usually vehicles or pedestrians. From a probability point of view, there is no doubt that the estimate of visibility should take into account the probability of the background being formed in this way. The more crowded the street the more the visibility will depend on this usually much darker background. It is true that under these conditions the areas of road surface which remain visible become of great importance to the driver, since they show up anything which encroaches upon them much better than the rest of the background. In general too, a driver regards a certain region of road around his vehicle as space which preferably should be kept free of other objects and he is especially on the lookout for encroachments on this particular area. But it is doubtful whether this dependence on the areas of road surface which are visible could justify us in omitting the rest of the background from consideration. This is just another case of our general ignorance of the real values of the probabilities. It is not known whether accidents occur in crowded streets mainly because objects are invisible against backgrounds of other objects until it is too late, or because the road surface which is available is not bright enough to reveal all the objects when they are viewed against it.

In extremely crowded conditions where very little road is visible it seems probable that the important background is mainly of vertical surfaces. Speeds would be low and danger distances short, so that vision of detail would increase in importance. Illumination on vertical surfaces would become more important in the end than illumination on the road surface, and this must have repercussions on the light output thought to be sufficient and on the best reflection factors for vehicles.

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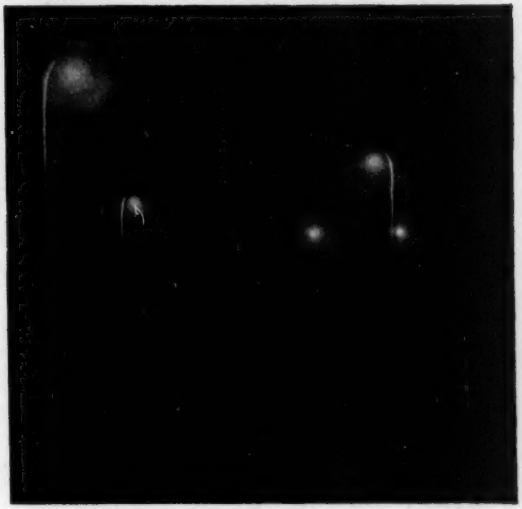

Fig. 1. Visibility in a street is usually based on the visibilities of objects in the street. These visibilities vary with object position, reflection factor, etc.

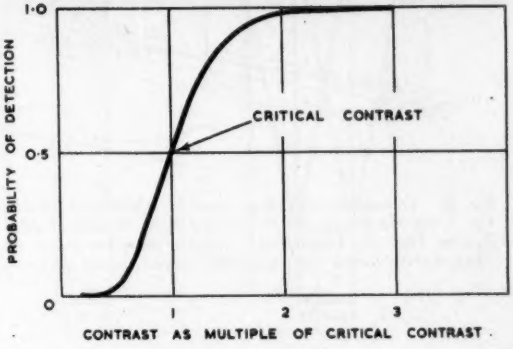

Fig. 2. Scales of visibility are not necessarily related in any simple way. Here a scale defined by the probability of detecting the object during a short exposure is related to the scale defined by the contrast between object and background.

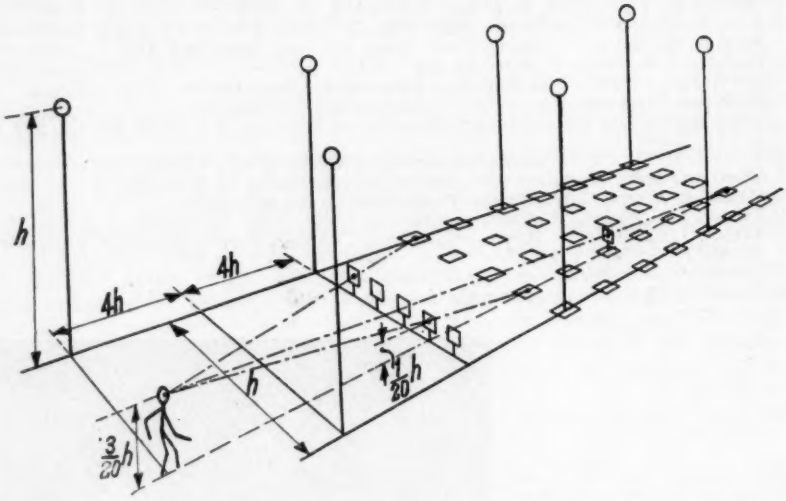

Fig. 3. To evaluate the visibility in a street, the visibilities of a representative collection of objects are first found. This shows the arrangement proposed by de Boer. Observer position is fixed, and 35 standard objects are viewed against 35 standard points of the road surface as a background.

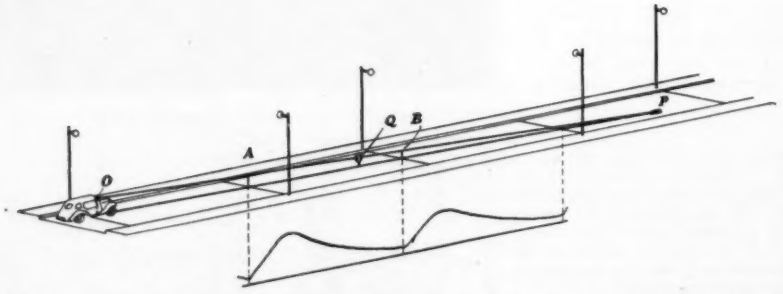

Fig. 4. To evaluate revealing power by Waldram's method, the observer position is fixed as in Fig. 3, but the objects are distributed along the line of sight OP and have a range of reflection factors. They also experience a range of illuminations as shown in the lower part of the figure. Thus, a great number of objects are viewed against each element of road surface, not just one.

Fig. 5. Revealing power contours. The figures denote the percentage of objects along the line of sight which reach an "adequate" contrast with the road surface.

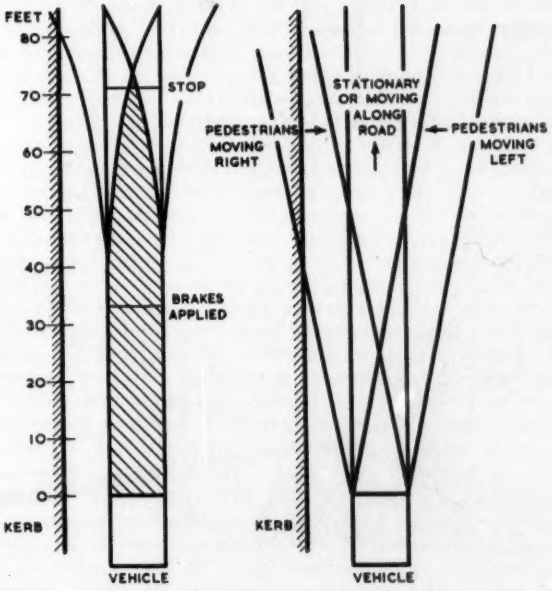

Fig. 6. Danger and visibility for a vehicle and pedestrians. If a driver suddenly sees an obstacle he can brake or turn, but a certain part of the road ahead of him, shown shaded in (a), cannot be avoided. Pedestrians who will be hit by the vehicle unless they take avoiding action or the vehicle changes motion are in the three lanes shown in (b).

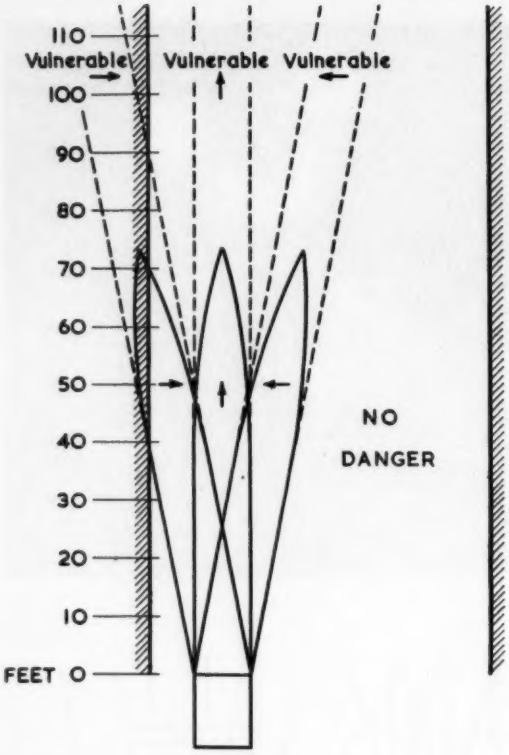

Fig. 7. A combination of Figs. 6a and 6b. There are three zones of unavoidable pedestrians. These represent regions of extreme danger. Outside them the danger level falls off fairly rapidly. This pattern of danger moves along with the vehicle.

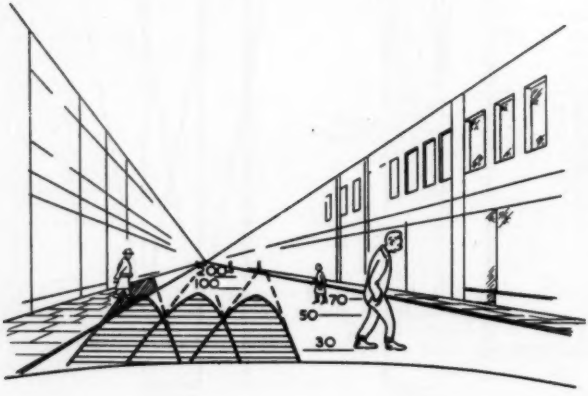

Fig. 8. Danger zones of Fig. 7 shown in perspective. The danger pattern and the visibility pattern in the street must be combined in some way to give the visual safety pattern.

Discussion

DR. W. S. STILES: In recent years illuminating engineers have concentrated on providing installations which are comfortable, that is to say, free from positive sources of discomfort, such as glare, and having at the same time aesthetic appeal. Mr. Harris, in his careful exposition, brings us back to the old objective of lighting for visibility. But here I must be careful, for his main contention, as I understand it, is that the objective is really visual safety and that past attempts to assess figures of merit for visibility or revealing power in a streetlighting installation or for a headlight system have ignored or misconceived the safety aspect. I would not wholly agree with this. The more elaborate attempts to derive aggregate visibility factors, such as Mr. Waldram's 1938 paper on revealing power of streetlighting installations and the method for evaluating headlight glare given by Mr. Dunbar and myself in 1935, did try to weight the component visibilities so as to allow, in a rudimentary way, for some of the factors Mr. Harris has stressed. But we must agree with him that the available information about the importance, from the safety standpoint, of visibilities for different object positions and directions of view is extremely meagre. Work being done by Mr. Harris and his colleagues at the Road Research Laboratory will I believe materially increase our knowledge on such points.

However, it seems to me that there are dangers in a too exclusive pre-occupation with accident rates. I have the impression from what Mr. Harris says that if it were practicable he would like to let loose an expendable and inexhaustible population of drivers and pedestrians in any installation for which he wished to know the aggregate visual safety factor. After a fixed period—it would have to be a very long one to smooth out statistical irregularities—he would tot up the number of dead and injured. This would give him an answer by which he could rank installations in order of merit, strictly on a safety basis. But would that really give what is wanted? Mr. Harris himself draws attention to a factor which makes it very doubtful. Drivers adjust their driving, particularly their speed, to their own subjective estimates of the visibility conditions. Mr. Harris argues from this that to deduce probable accident rates from visibilities for standard fixed conditions is invalid. But it may equally well be said that to draw conclusions about the effectiveness of the lighting from accident rates is also unsound. One thing that has been left out of account is the average speed of traffic that will be achieved in the installation. I am assuming that one main purpose of a road is to enable vehicles to pass expeditiously from A to B, and that in an installation where the average speed is higher the lighting has achieved some positive good which may be set against the positive ill of a higher accident rate. The various ways of defining an accident rate have a bearing on this argument, but it remains true, I think, that freedom from accidents cannot be the only criterion of the visibility provided by an installation. Perhaps accident rate could be used if it were stipulated that the volume and speed of traffic were maintained at constant fixed values. The idea would be to eliminate the "negative feed-back" of the driver's subjective estimate of the visibility. But the empirical accident rates measured under unrestricted conditions would not be applicable. In some comparisons, the restriction imposed by a 30 m.p.h. limit if faithfully observed might validate a comparison of empirical accident rates. But in general, I think, an experimental approach perhaps by full-scale trials, with dummy objects, in which the vehicle speeds could be pushed up to produce relatively high "accident rates"—a kind of accelerated life and death test—might be more informative.

I was struck by the vacillations in Mr. Harris's analysis, vacillations which I think were inevitable in any honest attempt to face up to this difficult problem. He laid down that to assess the visibility in different installations it was necessary to combine individual visibilities into a single figure and he argued that this could only be done by using the criterion of safety, preferably expressed in statistical terms. But this

he showed would be extremely difficult, particularly as he would include the negative feed-back I referred to earlier. He inclines, therefore, to accept a weighted sum of individual visibilities, on the strict understanding that this is to be understood as an approximation to the ideal aggregate visual safety factor. He is not very satisfied with this and at this point he really throws overboard the single aggregate visibility factor or figure of merit, and for the present at any rate he plumps for one to one comparisons of individual visibilities in different installations. This is suspiciously like the position of earlier investigators who have ventured to derive single figures of merit for the visibility in an installation. They emphasised the danger of staking everything on a single figure and the need to look also at where visibility is high, where it is low in different installations.

This may sound like saying to Mr. Harris "Was your journey really necessary?" On the contrary, a periodic re-examination of the basis of our attempts to assess visibility in an installation is essential, and it seems to me that Mr. Harris's very careful analysis puts many points in a new light and will repay very close study by everybody working on these problems.

MR. J. M. WALDRAM: I have a special reason for gratitude to Mr. Harris for his clear analysis of this difficult problem. He mentioned the question referred to a Working Party at Zurich; I was responsible for putting this question, but I did not then know that a working party would be appointed, nor that I should be appointed its chairman to answer my own question. I am, therefore, specially grateful to Mr. Harris for his notable contribution to the answer.

He has shown something of the complexity of the problem; but even in his paper all the points do not appear: he will no doubt agree that it is even more complex than he has assumed. When Mr. Smith and Mr. Dunbar and I were working on this problem in an investigation to which he has made a very kind reference, we were convinced that any formal expression of "visibility" must conform to the popular conception of "visibility"; if it did not, it would be discredited. And since no two people mean the same thing by this word, the chance of success of any formal expression is not high. An example is to be found in a well-known installation in the Sidcup Bypass, lighted by cut-off lanterns on the centre reservation. When this design was suggested by a colleague of mine, I was bold enough to say that I did not think it would succeed, for reasons which seemed good. But, in fact, it was hailed as possessing "excellent visibility." Probably some of the characteristics which contributed to this opinion are the regular and tidy arrangement of lanterns, the excellent guidance which they give, and the smooth brightness distribution and the comfortable result. Yet I believe that the revealing power near the outer kerbs is comparatively poor, and the installation has certain other defects, not obvious to the general user. But any system which rated such an installation low would certainly be condemned.

It is important to consider what happens as the conditions for seeing improve. If they are very bad, a given object will never be seen. As they improve, it will be seen occasionally, then on about half the number of presentations (the threshold), and eventually (at about twice the threshold) on every presentation. Further improvement cannot make the object more *detectable*. But it may make it more *conspicuous*, and it is some measure of "conspicuity" which is given by the meters which degrade the conditions until an object disappears. But even conspicuity is not all; there is another factor not mentioned by Mr. Harris which was called in about 1927 the *noticeability* of the object—a horrid but expressive term. The girl in the back row of the chorus is not invisible; she may be quite conspicuous. But she does not compete with the star in the limelight. She is conspicuous, but we were looking at someone else. Street lighting has not merely to make things visible; not merely even to make them conspicuous; it has to make the right things obvious. For example, lighting which con-

centrates attention on the centre of the road and diverts it from the kerbs is at fault, though few would spot it.

Thus far I would agree with Mr. Harris that we must include the notion of safety. I am not sure that I go all the way with him in including safety in visibility. In a sense lighting is neither safe nor unsafe. Its job is to give road users all the necessary information clearly and with the right emphasis, and that is all that it can do. When it has done that, it is up to the road users, and it is they who are safe or unsafe.

In such a problem as this, definition is vital; you can neither measure nor calculate a quantity unless you can define it. But "visibility" is surely the most ill-used word in our technical vocabulary. It has meanings in physiological optics and in meteorological optics, quite apart from street lighting, some of them confused. Mr. Harris has shown that as applied to streets it may mean:—

How *well* do you think you can see?

How *conspicuous* is an object?

How much can the view of an object be degraded (in different ways) before it cannot be seen?

What is the least contrast that can be seen?

How *far* can an object be seen?

How *quickly* can an object be seen?

How *many* such objects can be seen well enough for driving?

How *safely* can you see?

each of which has several variants.

I do not think, and I believe that Mr. Harris agrees with me, that we shall or can ever get a valid and reliable overall measure of either visibility or visual safety; and instruments and measures which are misleading are worse than useless. If Mr. Harris has done no more than state clearly that "the following ideas won't work," he has done us a great service. If this is right, then I suggest that the best thing to do is to define precisely some relevant quantity, such as revealing power, which goes a part of the way; give it a name which is self-explanatory and which is neither "visibility" nor "visual safety," recognise clearly its limitations, and use it as an ingredient in the informed judgment of a technical man. That after all is what happens with almost every engineering measurement.

MR. F. C. SMITH: The paper by Mr. Harris is thought-provoking and his introduction, stimulating and helpful. As a member of the technical panel, which was set up by the Interdepartmental Committee appointed by the Minister of Transport to study street lighting, and which reported in 1937, I well recall that one of the tasks given to the panel was to suggest a "yard-stick" which would provide a means of assessing the relative effectiveness of street lighting installations. Questions involving safety were well to the fore throughout the investigations.

Mr. Harris has paid tribute to the usefulness of the concept "revealing power," but has suggested that it was not altogether successful as an indication of the safety provided by a lighting installation. It is agreed that two street-lighting installations could have virtually the same overall revealing power but could well provide a different degree of visual safety in different parts of the streets, and that these differences could occur in some installations at places of greater hazard than in others. I must say that the panel never did regard "revealing power" as a yard-stick to measure the relative merits of street lighting installations, but were of the opinion that the pattern revealed by such diagrams as were produced by Waldram and others during this development gave a great deal of information as to the probable effectiveness or otherwise of a given installation, and were well aware that "dark" patches, even if of the

same area, in some parts of the street scene constituted a greater hazard to visual safety than those in other places on the street.

Even a street with an ideal lighting system is still a place of hazard for those using the street who are preoccupied, or have inferior sight, and/or poor hearing, or on account of advancing age have diminished alertness and slower response, to say nothing of persons who are careless of their own or other people's safety. Lighting alone cannot guarantee safety at night, but I agree with Mr. Harris that there may be certain potentially dangerous positions, which may be made less dangerous by well-planned lighting or other means.

Dunbar determined for a large number of drivers of various ages, etc., the difference of brightness necessary between the object and its background to ensure that the object was revealed in silhouette in time for the driver, proceeding at 30 miles an hour, to take the appropriate avoiding action. These measurements were made at various field brightnesses. This work dealt with a factor of the greatest importance in securing visual safety on the streets at night.

The panel also studied the relative merits of installations having lighting units suspended centrally over the carriageway, as compared with those having kerb-mounted or overhung units. It reported unfavourably on the use of central suspension for wide roads for a variety of reasons, among which were that the kerb was not always well-defined, and there could be " lanes " of darkness in the area of the carriageway adjacent to the kerb-line. This was a clear recognition that certain areas of the street might well represent zones of greater hazard than others.

The carriageway is by no means the only background against which objects on the road, or objects about to enter the carriageway, are seen. During the time the committee was sitting a film was taken from the front seat of a car over a journey of several miles in the town and suburbs in the daylight, in order to establish the backgrounds against which objects were seen by the driver of the vehicle. This showed the importance of backgrounds other than the carriageway. Perhaps the most important information obtained by the panel was the insight gained from the very extensive series of experiments on desirable features for the design of street lighting installations.

MR. W. ROBINSON: The author, in his written paper, raises the matter which seems to me to be of considerable importance in connection with the assessment of visibility, or particularly of visual safety. He points out that the driver adapts his driving, and particularly his speed, to his own judgment of how well he can see. This judgment, of course, varies from driver to driver in any given situation and the main danger occurs when the judgment is unduly optimistic. Obviously then, there is another variable introduced into the subject and we must modify the effect of degrees of visibility by weighting it with the driver's reaction to it. This brings out what is probably the most important feature of street lighting, namely that it must not create merely an illusion of good visibility, for such lighting is probably far more dangerous than lighting which is so obviously bad as to incline the driver to greater caution.

Reference has been made in the discussion to the fact that street lighting cannot cope with all the vagaries of pedestrians, and I would also suggest that street lighting cannot cope with situations created without regard to its limitations. I refer particularly to the recent announcement from the Ministry of Transport that the provision of street lighting along a road will not in future automatically involve the restriction of that road. I regard this as an extremely serious innovation, for what it means in fact is that drivers are to be permitted, and even encouraged, to proceed at unlimited speeds on a road which is lighted specifically for safe movement without headlamps up to a maximum of 30 miles per hour. It is certain that many drivers will rely on sidelights at speeds even up to 60 miles an hour. If drivers do put on their headlamps the situation is little better because the mixture of direct lighting from the headlamps and

background lighting from the street lights is not a happy one, as the two methods tend to cancel rather than to build up visibility. It would be interesting to have an assessment of visibility in this particular condition.

MR. R. STEVENS: The author has introduced the new concept of visual safety and makes a distinction between the actual visibility or revealing power and a driver's subjective estimate of the visibility or the apparent visibility. As Mr. Waldram has indicated, these last two factors may be quite unrelated in any particular installation, and Mr. Harris has pointed out that a driver's reaction to the apparent visibility is to reduce his sense of danger to some acceptable level. If, therefore, safety is the only criterion, we have the somewhat paradoxical concept of the perfectly lighted street; it is one in which apparent visibility is low but actual revealing power is 100 per cent. Visual safety will then be at a maximum. As a corollary a road, such as the one mentioned by Mr. Waldram, where apparent visibility is high but measured revealing power is low, may have a low safety rating.

MR. G. K. LAMBERT: It appears to me that the value of ranking installations on any single criterion, however meaningful, is less than a knowledge of the constituent factors—road brightness and its pattern, revealing power and glare effects. The interpretation of these may be empirical, needing experience, but for visual safety a route must be satisfactory in each of a number of respects, particularly as regards adequate illumination for seeing nearer objects.

"Visual safety" is a very comprehensive term. Mr. Harris has indicated the change in emphasis from "revealing power" to "adequate illumination" for seeing closer objects in heavily trafficked streets. Would Mr. Harris give his opinion regarding the importance, as regards visual safety, of guidance to a stranger approaching a complex junction under such conditions, and also as regards choosing and maintaining his position in the correct traffic lane? What visual information does he need?

MR. R. L. MOORE: I think I detect a note of pessimism in the words of some of the speakers; the feeling that we are never going to be able to compare, unequivocally, one street-lighting system with another. However, if Mr. Harris's thesis were adopted and visual safety were used as the measure of street-lighting performance, given sufficient accidents and therefore sufficient time, an answer would eventually be found. The difficulty lies in waiting long enough for the answer, and I wonder whether lighting engineers would be prepared to accept answers from a speeded up experimental situation. In the early days of the study of revealing power, as Mr. Smith has described, daylight cine-photography was used to find the background against which objects were seen. Nowadays it is possible to take cine-photographs in lighted streets and actually determine the contrast ratio and position of pedestrians, cyclists, etc., as they are seen at night. With this information it would be possible to arrange for dummies to appear in an experimental street scene and to measure the chances of a driver detecting them in time to take avoiding action.

It seems to me that insufficient attention has been paid in the past to the perceptual load on the driver. Things are no doubt visible, but there is a limit to the amount of visual information which the driver can absorb: this might be an important factor in busy streets.

MR. R. PELERIN: I suggest that the visibility rating of street-lighting installations should be related to traffic loading on the street. In main squares, junctions and streets in large cities, at the peak of the rush hours, silhouette vision is impracticable because the street is filled with large transport vehicles (buses, trolley buses or trams), other wheeled traffic and many pedestrians all anxious to go their particular ways

in the shortest possible time. The same areas and streets at midnight are usually empty, and silhouette vision allows any obstruction to be seen easily at a good distance. The visibility ratings for these two sets of conditions are very obviously different.

MR. A. G. PENNY: I would like to support Mr. Pelerin in his remarks about the need to consider visibility on the road in relation to modern traffic conditions. I regard the last paragraph of Mr. Harris's paper as, perhaps, the most important. The present technique of designing street lighting was, as we have been reminded by Mr. F. C. Smith, based on a consideration of conditions over 20 years ago. At that date the general performance of cars was much poorer, especially in regard to acceleration whilst there were only half the number on the road as compared with to-day, and they were smaller. I feel that to-day there is a need for the evolution of a new technique of street lighting in which we might incorporate factors not previously considered.

For instance, we should give some attention to the psychological point referred to by Mr. Robinson, that roads should be safer than they appear. We might also remember the knowledge, acquired in regard to interior lighting, that an improvement in seeing conditions will only be significant if the level of lighting is raised by a factor of at least two (and preferably 10). As Mr. Carpenter has said, the real expenditure on street lighting is less to-day than in 1932, and I feel, therefore, a substantial increase in the lumens per mile of road is easily justified. But if we cannot, for financial reasons, put 10 times as much light on the road to help the motorist see, we should turn our attention to the possibility of ensuring that the unattentive pedestrian is made aware of the approach of a car *before* he steps into the danger zone. The American practice of the compulsory use of headlights in lighted streets is something we should consider. Just because we so often see in daylight by silhouette against a bright background, we should not assume that this is the best technique to apply for lighting after the sun has set.

MR. HARRIS (in reply): I attempted in the paper to discuss and compare the various definitions of visibility which have been put forward. This may account for some of the apparent vacillations which Dr. Stiles detected: I was not committed to any one particular point of view from the beginning. But I did make the assumption that fundamentally we would be satisfied with an assessment based on safety alone and would not be satisfied with one that did not take safety into account. The criterion of safety was the accident rate. Dr. Stiles has quite rightly questioned this assumption, pointing out that we might value an increase of speed even if it involved an increase in the accident rate. If this were so, our criterion would depend on accident rate and traffic flow, and the idea of a figure of merit based on safety alone would fall to the ground. But this additional complication would not affect the argument, on which I laid some stress, that the visibilities of objects in the street are themselves incapable of supplying an acceptable figure of merit. It would mean that the destructive criticism already applied to the aggregate visibility factor could be applied to the aggregate visual safety factor also. I was less concerned to establish visual safety than to show that visibility alone was inadequate as soon as any weight at all was given to the safety aspect. I am not certain that I have made it clear that this is a logical difficulty, not simply a practical one.

If we agree, for the moment, to assess the lighting by means of the accident rate, and to assess the accident rate experimentally, then I would not agree with Dr. Stiles in wishing to keep both the traffic flow and the traffic speed constant. Given the traffic flow, the speed can be allowed to adjust itself to the lighting in the normal manner. It is true that one can regard the change in safety following a change in lighting as due partly to the change in visibility and partly to the change in speed. But as the speed

normally follows when the lighting and traffic flow are given, there seems to be little value in trying to divide the effect into two parts. If, by special measures, one could cause the traffic to move at the original speed, I should prefer to regard the result as due to a combination of improved lighting and special measures rather than as the pure result of the lighting.

Dr. Stiles suggested that full scale trials at greater speeds, producing increased "accident rates" for dummy pedestrians, would be more informative than studies of normal accident rates. I am sure such investigations would be very valuable in deepening our understanding of how accidents occur, especially if we measured the distances at which things were seen and avoided and not merely counted the collisions. I am not so confident that they would quickly give us a comparison of two installations. For the comparison to be reliable the installations should be compared at the levels of traffic the road would actually carry, not at high flows and high speeds which would not be reached in practice. Accelerated tests would help us to discover what might be called the general laws of accidents, but would be less effective in determining the parameters appropriate to the practical situation. I have no doubt, however, that they would give us very valuable information.

Mr. Waldram feels that the word visibility has too many meanings to be really suitable for technical use. I agree with this but I am not clear how to get over the difficulty. Revealing power is a more expressive word than visibility and has a clearly defined meaning. But there is nothing to prevent someone from proposing a new scheme of numerical computation and saying, "This new quantity measures the capacity to reveal even better than revealing power." As the name "revealing power" has already been allotted we should have to invent a new name for each new quantity proposed in this way. We should then have a multiplicity of names for quantities all of which were thought to be attempting to express the same thing. We should then require a name for this thing they were trying to express. Perhaps we should call it revealing power, but then the term would have to lose the precise meaning it has at present.

If we have a precise term we can calculate its value but we are unable to prevent rival claimants from springing up. If we have a vague term, then we cannot decide exactly how to calculate it. These difficulties are connected with the logical difficulty that visibilities alone provide no basis for an order of merit. The visibilities only provide a criterion when all the visibilities in A are better than the corresponding visibilities in B. We may then say the visibility in A is better than in B; but if this situation does not exist we cannot say anything at all as to an order of merit. Unless, when we are trying to judge installations and put them in order of merit, we use a criterion which is logically capable of giving an order of merit, these difficulties cannot be avoided.

Mr. Waldram draws a distinction between visibility, conspicuity and noticeability. From the point of view finally adopted in the paper, all these have their place on a single scale of visibility. This scale was to be provided by the probabilities of detecting these objects on the road. To take Mr. Waldram's own example: if an object is seen in 50 per cent. of presentations at threshold contrast and in 100 per cent. of presentations at double the threshold, I would accept the fact that there was no increase of visibility at higher contrasts. Under the conditions of the test, these higher contrasts contribute nothing to facilitating the task. But if the task is made harder the threshold contrast rises and objects which previously were of equal visibility may now become unequal. This is a consequence of adopting a view of visibility which includes the state of the observer, and the difficulty of his task, as well as the brightness distribution and other features of the field of view. This was 'the view adopted in the paper, but I do not feel so sure now that it is the best for the street lighting problem. I suggested that the proper scale for visibility

was one expressed in terms of the probabilities of detecting the objects under actual road conditions. But it had to be admitted that these were at present unknown, because of the feed-back effect and because the driver's task at any moment might be greatly increased in difficulty owing to the presence of other vehicles. We cannot in fact measure visibilities on such a scale. I now think it may be better to use what I called the basic visibility, a visibility measured under some standardised conditions, and therefore expressible in terms of the field of view alone. This is really more in line with what has actually been done in most cases, for example, the use of visibility meters, or the computation of revealing power, which is derived solely from the brightnesses and illuminations in the street and a criterion obtained under fixed conditions. Indeed, we can probably do without visibilities entirely if we wish. What are provided in the street are brightnesses and illuminations, and it is these which determine the visible aspect of the street, and therefore the visual part of the safety. There is clearly no need, except possibly one of convenience, for creating entities such as visibilities and interposing them between the brightness at one end and the accidents at the other.

Mr. Smith points out, and I entirely agree, that the auhors of revealing power were well aware of the safety aspect and of the fact that different parts of the background might be of different importance. What I wished to emphasise, however, was that the calculations give us numerical values of revealing power which are perfectly correct and meaningful in their own field but that this is not the field of visual safety, with which, I assumed, we were ultimately concerned, and in this field the exact figures of revealing power cease to have any exact meaning. When we have calculated our revealing power and drawn our diagrams, we wish to interpret them. Being aware of the importance of safety we try to interpret them in terms of safety and we find that we have no clearly defined way of doing it. This is not a criticism of revealing power or of those who devised it. This gap in our knowledge exists. We have to admit, when it comes to the point, that the exact numbers we have calculated do not convey an exact meaning because the information essential to their interpretation is lacking.

Mr. Smith also pointed out that the importance of backgrounds other than the road surface is generally recognised. I agree, but I think it is true that they are not catered for in any of the systematic methods of assessing the visibility in an installation.

I agree with Mr. Robinson and with Mr. Stevens that, if an installation which gives good visibility can give an impression that the visibility is poor, then it is an even better installation. But I do not know how to achieve that effect.

Mr. Robinson raises the question of high speeds on lighted roads when there is no longer an automatic imposition of a speed limit. There is little doubt that the absence of a limit will make the roads more dangerous, but I do not think we have enough information to estimate the effect. If the street lighting is up to good present-day standards I do not think that the use of dipped headlights would normally be of much effect.

Mr. Lambert suggests that a knowledge of the ranking of an installation according to any single criterion is less valuable than a knowledge of the constituent factors on which that criterion was based, because the latter allows one to judge whether the installation is satisfactory in each of a number of respects. This seems to be defensible, provided one believes that installations must be judged in a number of ways and that it is impossible to combine the results into a single criterion, i.e., an order of merit. If, however, the single criterion exists but we are unable to determine it because we lack the necessary information (as, for example, we may suppose to be the case for visual safety) we can still determine whether the installation is satisfactory according to the individual criteria. Judging whether an installation reaches a satisfactory standard, and placing it in an order of merit are distinct operations. For this reason visibility remains a highly important factor even though it cannot by itself form a basis for an order of merit

To answer Mr. Lambert's final question about visual guidance at a complex junction would require more knowledge and invention than I possess. I can only suggest that the driver requires signs of such a size and sited at such a distance that he can read them without having to slow down or deflect his gaze far from the direction of motion, and that the layout of the junction should be made clear on the signs and as far as possible on the site itself. But exactly how this could best be achieved I cannot say. Each junction would probably have to be studied individually.

Mr. Moore, like Dr. Stiles, believes in the value of a speeded-up experimental investigation, and I have dealt with that point already. I agree with Mr. Moore that the recent development of much faster photographic film does greatly increase the facilities which may be exploited in this field of investigation.

The perceptual load on the driver is of great importance as Mr. Moore suggests. The fact that it may vary rapidly with changes in the traffic situation may invalidate the rather simple view of visibilities and probabilities of detection which I adopted in the paper. As I indicated in my reply to Mr. Waldram, since we cannot include the driver correctly in the measurement of visibility we might as well eliminate him from the definition of it.

I am in entire agreement with Mr. Pelerin that the assessment of the visual safety of an installation must be made afresh for each value of traffic flow. I also incline to the view that for very crowded conditions one needs to see by contrast and surface detail and that the road surface plays a smaller part. Mr. Penny agrees with this and urges it more strongly than I did. He also thinks that it might be a good thing, on roads lit to a less than adequate standard, to use dipped headlamps as an added warning to pedestrians. I have never liked this idea, though we have no evidence as to its value. The dipped headlight is a nuisance to other drivers because of its greater glare. It is certainly a more noticeable light than the sidelight, but whether its use would lead to pedestrians forming a better judgment of the position and motion of the approaching vehicle is more debatable. The glare of the lights tends to make the vehicle itself invisible, and it seems to me that it would be better to illuminate the vehicles themselves, so that their outlines become visible, rather than to increase the power of what often appear as disembodied lights whose position it is difficult to judge.

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